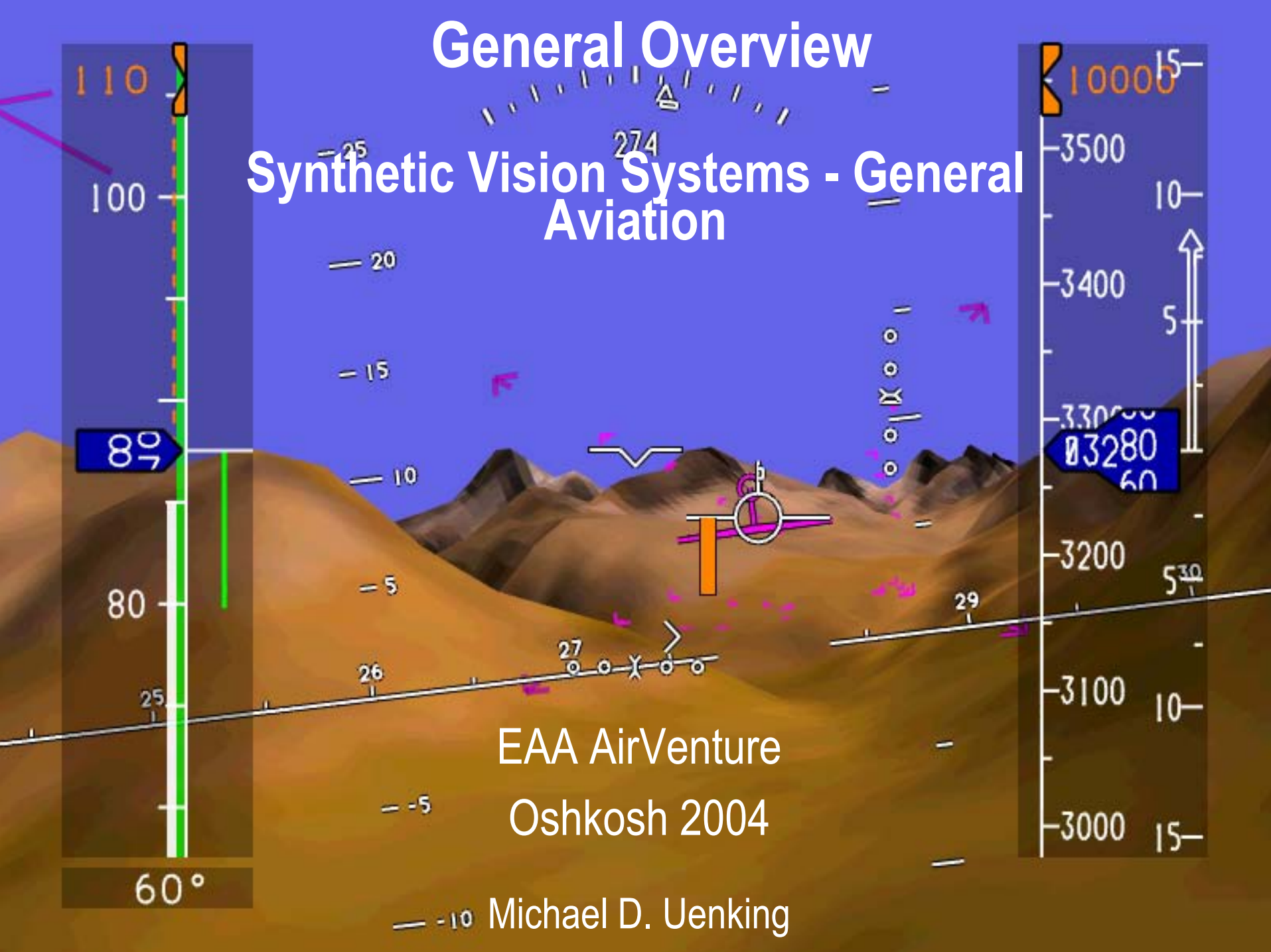

General Overview
Synthetic Vision Systems - General Aviation
EAA AirVenture
Oshkosh 2004
Michael D. Uenking

Outline of Presentation

- Aviation Safety and Security Program (AvSSP)/Synthetic Vision Systems (SVS)-General Aviation (GA) Goals and Objectives
- Operational Benefits
- SVS Definition
- GA focus
- Research Facilities
- Research Performed to Date
- NASA/GAMA/FAA SVS Workshop 2004
- Current Research Effort
- Outside Involvements
- Summary

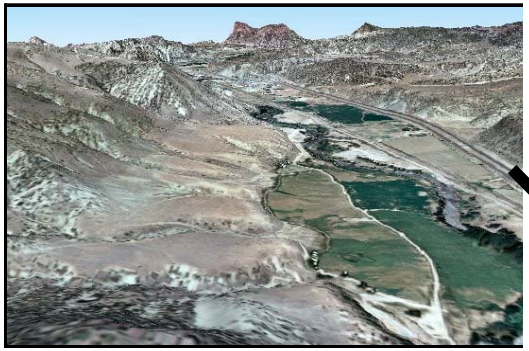
AvSSP/SVS-GA Goals and Objectives

The Aviation Safety and Security Program (AvSSP) is striving to reduce the frequency of fatal accidents and improve overall safety

- In support of this, SVS-GA has developed technology to:
  - Provide the pilot an unobstructed view of terrain, regardless of weather and/or time of day to enhance pilot's situational awareness (SA)
    - Reduce occurrence of Controlled Flight Into Terrain (CFIT)
    - Reduce Low Visibility Loss of Control (LVLoC)
  - Integrate advanced symbology
    - Drastically increases pilot performance
    - Maintaining or decreasing pilot workload
  - SVS terrain integrated with advanced symbology provides "Equivalent Safety" to day VFR flight

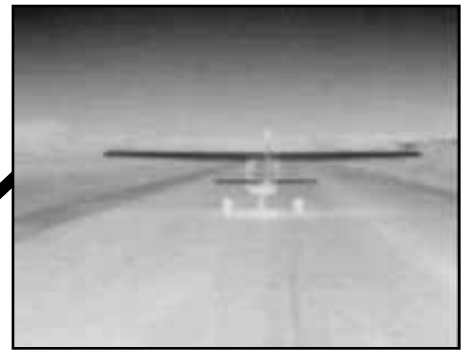
Synthetic Vision System Definition

Synthetic Vision Systems - General Aviation: General Overview

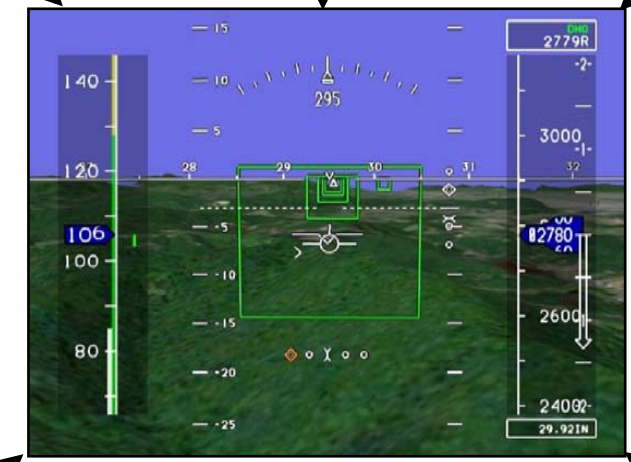


Worldwide Terrain, Obstacle & Airport Databases

Accurate Position and Orientation



Advanced Sensors for Database Integrity & Object Detection



Real-time Synthetic Vision Display w/ Advanced Guidance

Real-time tactical hazards (Weather, NOTAMS)

Relevant Traffic Information (ADS-B, TIS-B)

SVS Project Overview

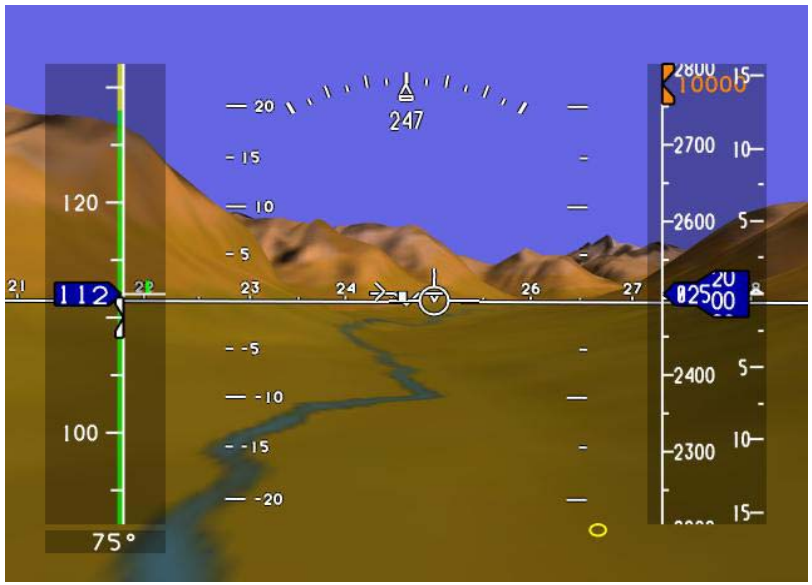
- SVS Project is composed of 3 elements
  - Commercial and Business Aircraft (SVS-CaB)
  - Enabling Technologies (SVS-ET)
  - General Aviation (SVS-GA)
- SVS-CAB
  - Focuses on issues particular to business and large jet transport aircraft
  - More expensive sensor augmented systems
- SVS-ET
  - Focuses on supporting technologies for SVS
  - Terrain database development
  - Terrain database verification and monitoring
- SVS-GA
  - Focuses on the particular needs and applications of GA aircraft
  - SVS core technology development

SVS-GA Focus

- Low Cost Baseline system:
  - Potentially no Sensors (outside of ADAHRS)
  - Potentially no HUD applications
- Operation independent of pilot background and capabilities
- Primarily employ existing strategic terrain displays primarily
- CFIT and LVLoC prevention
- Inadvertent IMC operations
- Different buyer motivations
  - Concerned with personal safety
  - General appeal

Operational Benefits

- A primary claim of SVS research is the ability of SVS displays to make IMC operations resemble those conducted in VMC in terms of safety and flexibility
- SVS must be shown to provide a level of safety at least equal to the conventional flight instruments it replaces



IV ?

Research Facilities

Synthetic Vision Systems - General Aviation: General Overview

- General Aviation Work Station (GAWS) capabilities
  - Integrated Elite simulation with SVS displays
    - Enhanced data output for research purposes
    - Can simulate several aircraft
  - 40 degree FOV front visual scene
  - Modular instrument panel configuration
  - Physiological data
  - Various audio/video recording
- Cessna 206 Capabilities
  - MX-20 Display (GPS, path, IFR, etc.)
  - Research computer integrated with ADAHRS
  - Research support enhancements
  - High capacity alternator
  - Substantial payload capabilities
  - Control/position transducers

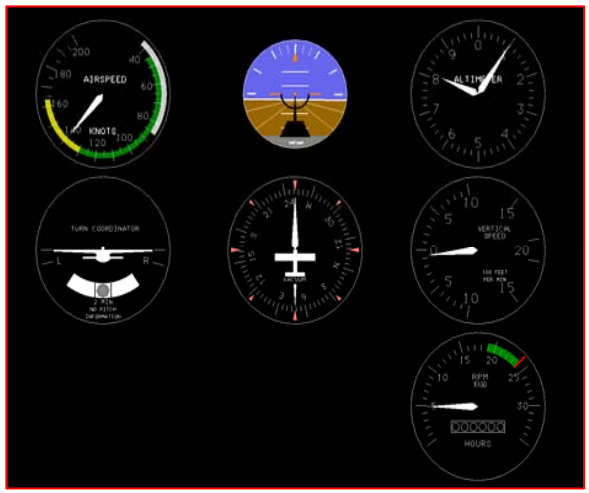
Research Performed to Date

Low Visibility Loss of Control (LVLoC) Experiment

- Provided:
  - Initial evaluation of inadvertent IMC encounter escape
  - First look at situation awareness (SA) improvements and pilot performance
  - Physiological measures were included
- 18 Low-time GA pilots in GA Work Station (GAWS)
- General enroute maneuvers
- Advanced symbology for GA
- Employed elevation-based generic (EBG) terrain database

Research Performed to Date - LVLoC

Synthetic Vision Systems - General Aviation: General Overview



Standard Flight Displays

LVLoC Display Types

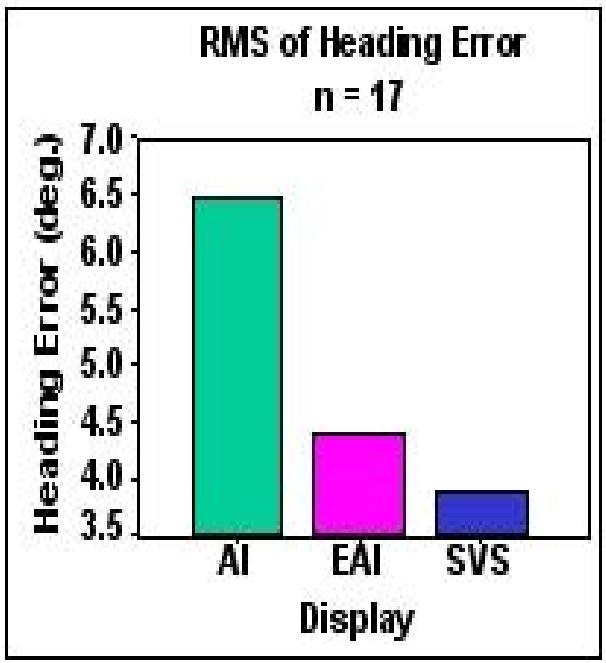
EAI Display Concept

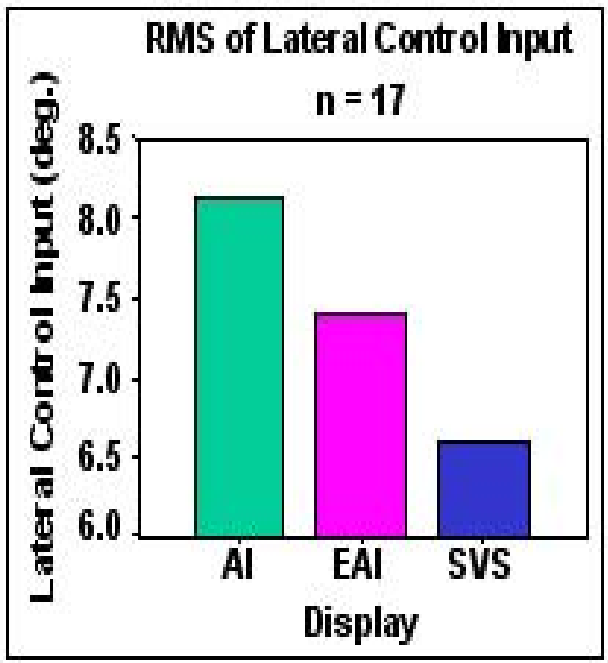
SVS Display Concept

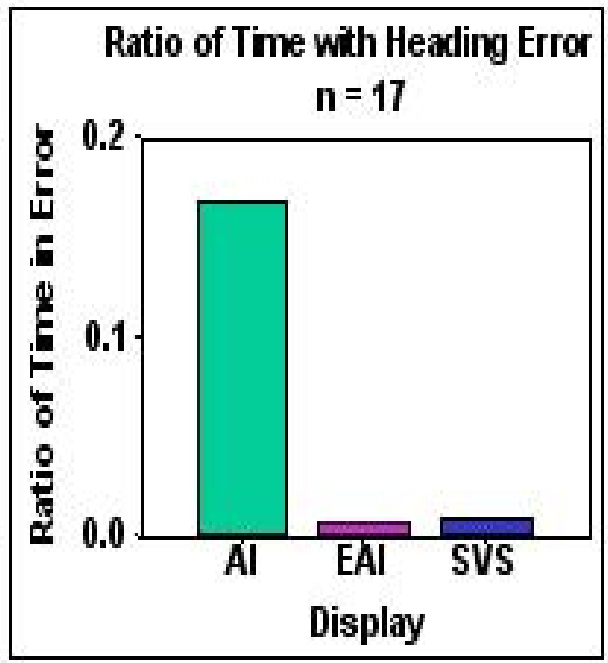
Research Performed to Date: LVLoC

Key Results from LVLoC

- SVS displays enhanced pilot performance and situation awareness
  - One pilot experienced a massive loss of SA with the baseline round dials







Research Performed to Date

Terrain Portrayal for Head-Down Displays (TP-HDD) Simulation and Flight Test Experiment

TP-HDD sim (GAWS)

- 27 pilots
- Included 10 SVS concepts and two baseline concepts
- Enroute, approach, and rare event maneuvers
- Evaluated tunnel on/off per FAA request
- Simulated Roanoke, VA (ROA)

TP-HDD flight (Cessna 206)

- 15 pilots
- Included 7 SVS concepts and a Blue-sky/Brown-ground baseline
- Enroute and approach maneuvers
- 2 sites (ROA and PHF)
- Approximately 90 hours of checkout and flight testing
- Complemented and extended ground based testing

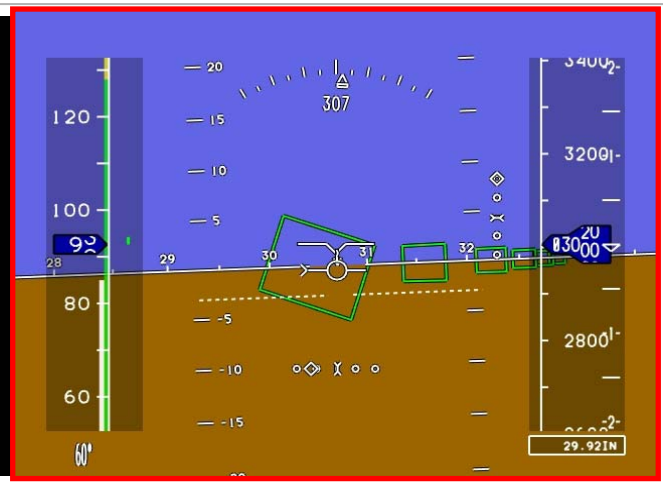
TP-HDD Experimental Variables

Synthetic Vision Systems - General Aviation: General Overview

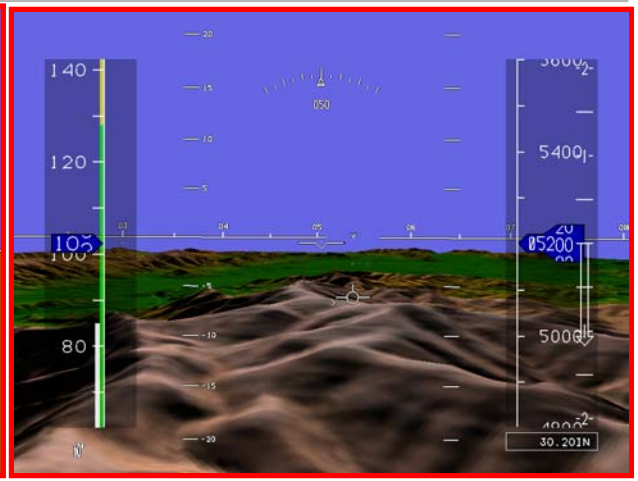
TP-HDD Simulation & Flight Test

Baseline Round Dials (BRD) → Blue Sky/ Brown Ground PFD → SVS PFD

- Airspeed, attitude, altitude, turn coordinator, directional gyro, and vertical speed indicator
- For approach scenario
  - Localizer/Glide slope deviation indicators
  - No tunnel

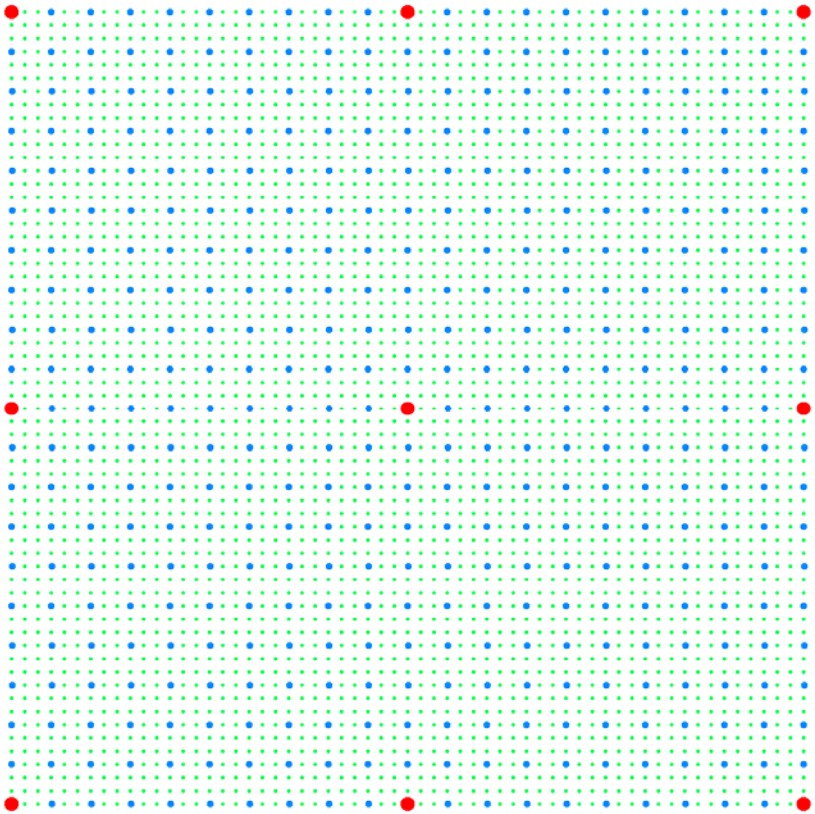


- Integrated Information on PFD
- Velocity vector with sideslip flag and acceleration caret
- Air data tapes
- Horizon line, pitch grid, roll scale with sideslip wedge and a digital heading
- Tunnel for approach scenario



- Terrain Portrayed
- FOV= 22, 30, 60 and 90
- DEM= 1, 3 and 30 arc-sec
- Various texturing
- Otherwise same as Blue Sky/ Brown Ground PFD

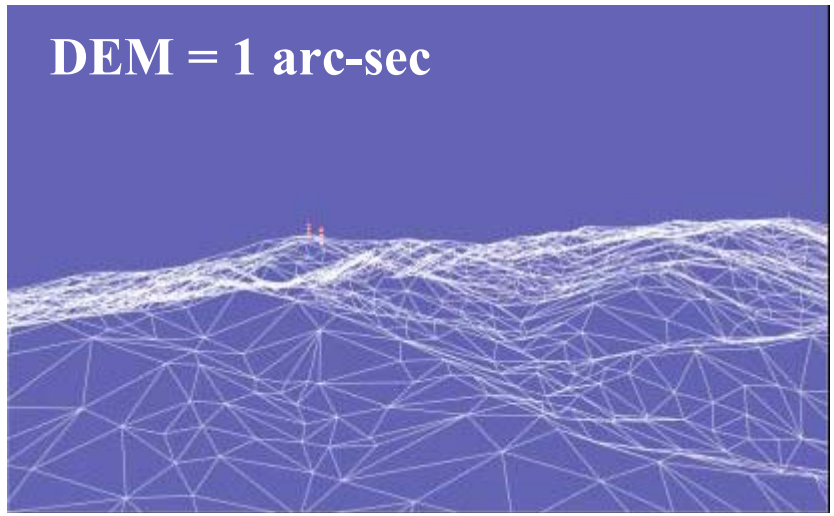
Terrain Portrayal: Digital Elevation Models (DEMs)

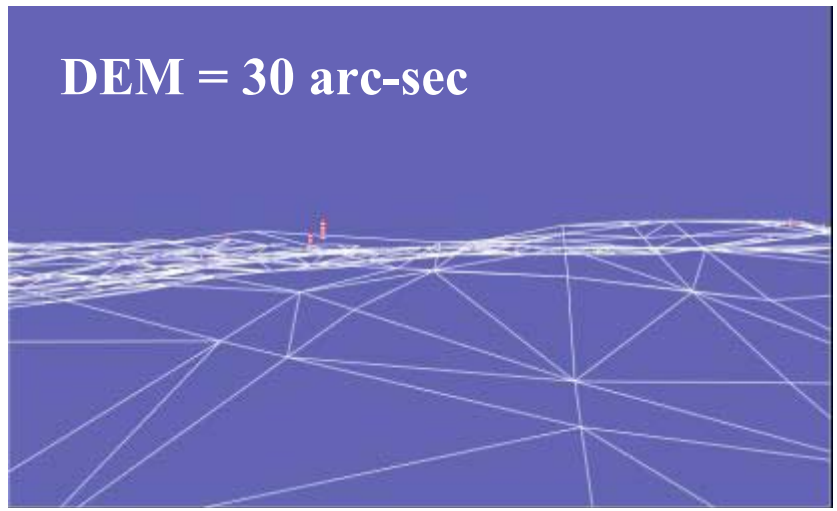


Green Dots: 1 arcsec ~ 30m

Blue Dots: 3 arcsec ~ 90m

Red Dots: 30 arcsec ~ 900m





Terrain Portrayal: Texturing

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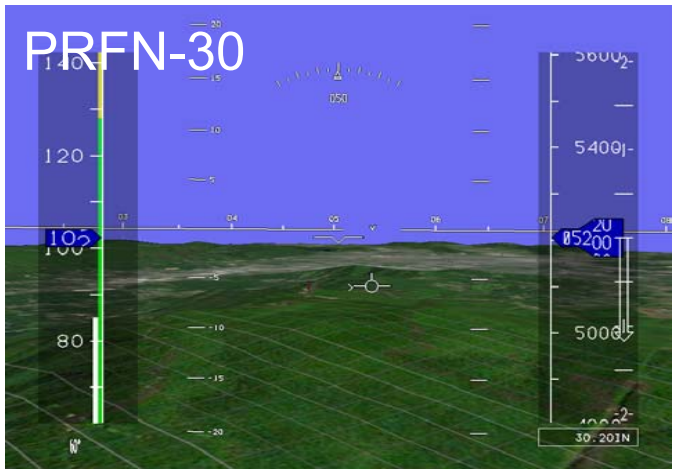
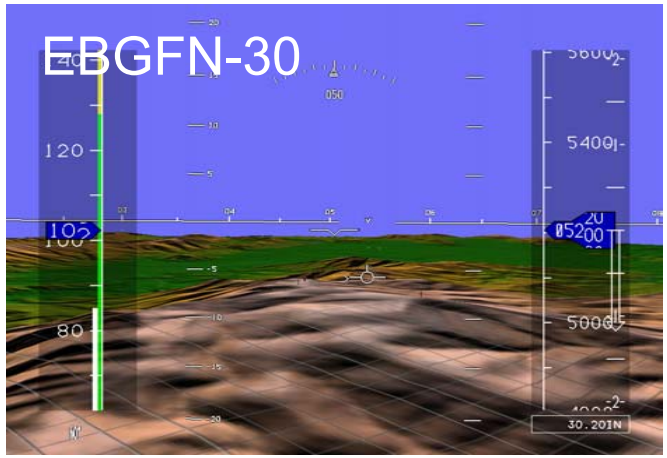
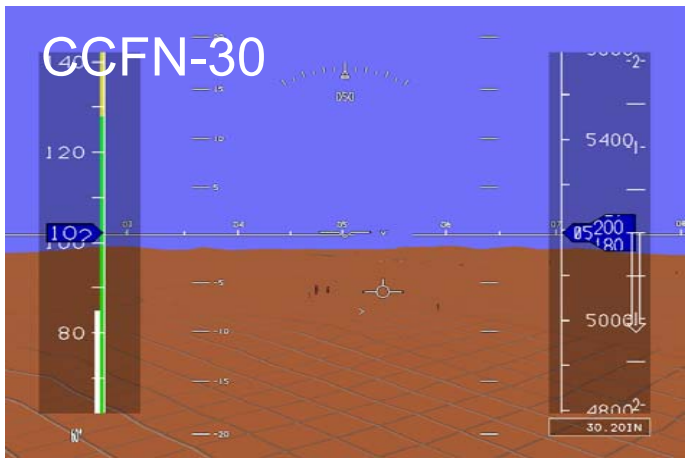


Photo Realistic Fishnet-30 Arc Sec



Elevation Based Generic Fishnet-30 Arc Sec



Constant Color Fishnet-30 Arc Sec

DEM/Texture Example

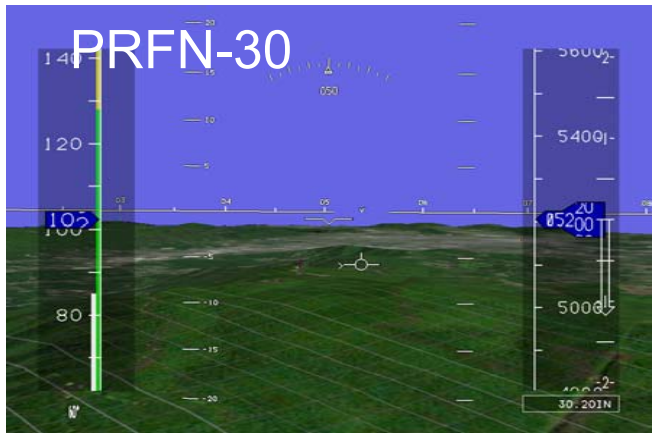
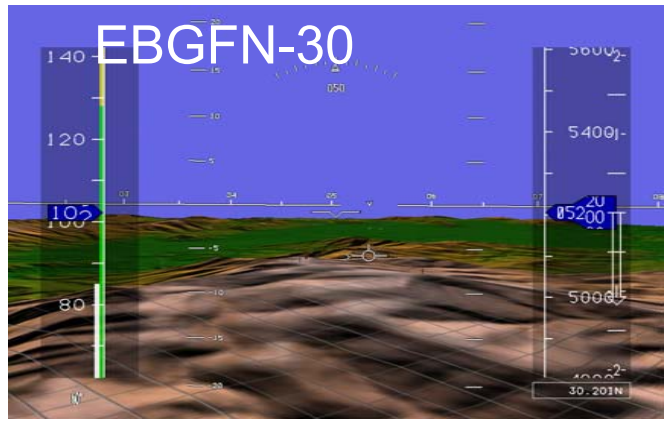


Photo Realistic Fishnet-30 Arc Sec



Elevation Based Generic Fishnet-30 Arc Sec

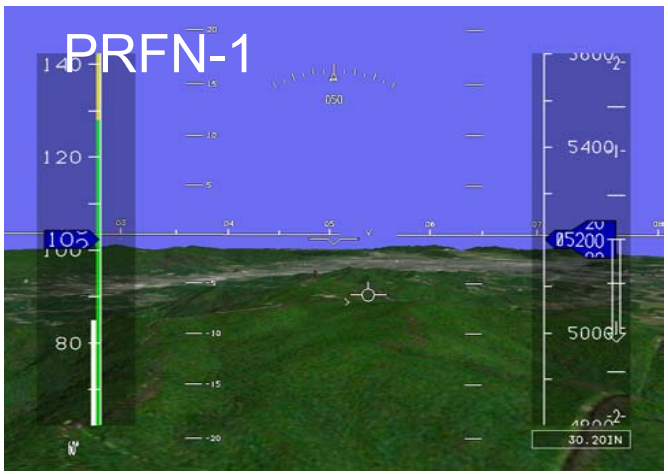
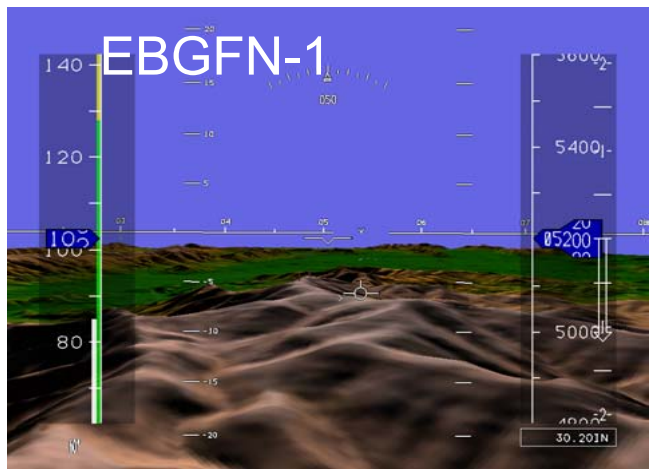


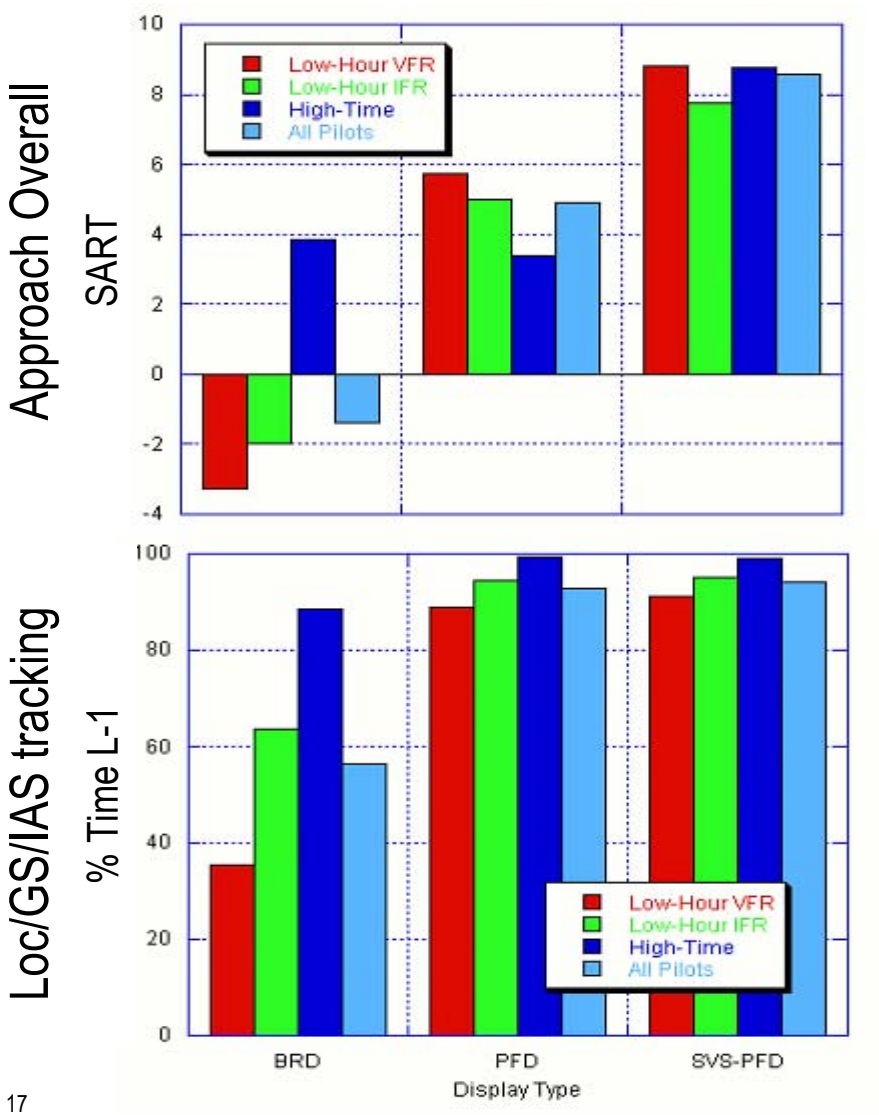
Photo Realistic Fishnet-1 Arc Sec



Elevation Based Generic Fishnet-1 Arc Sec

Research Performed to Date: TP-HDD

Key Results from TP-HDD



Legend: PFD: Primary Flight Display, BRD: Baseline Round Dials

- Situation awareness
  - SVS-PFD > PFD > BRD
- Pilot performance
  - (PFD & SVS-PFD) > BRD
  - Low-time VFR + IFR pilots with PFD and SVS-PFD flew as well or better than High-time pilots with BRD
    - Due to symbology (Tunnel)

Key Results from TP-HDD Simulation & Flight

Synthetic Vision Systems - General Aviation: General Overview

- Integrated Primary Flight Displays (PFD) with tunnel guidance improved pilot performance for both inexperienced & experienced pilots
- When terrain is added to the PFD:
  - Situation awareness was drastically enhanced, even with the most primitive SVS concept
  - Mental workload decreased
  - No degradation in performance
- Pilots preferred higher-res DEMs
  - 3 arc-sec was considered satisfactory
  - 30 arc-sec was least preferred, but still useful and better than standard gauges
- 60º field-of-view was the most useful
  - Different result than for air transport aircraft (due to lighter wing loading)
  - Lower field-of-view use possible only in calm conditions for GA
- Elevation-Based Generic terrain texture was found to be statistically equivalent to Photo-Realistic terrain texture in terms of SA and overall preference

Research Performed to Date

Symbology Development for Head-Down Displays (SD-HDD) Experiment Series

Part A Part B Part C

Establish interactions between Guidance Symbology and Terrain Portrayal concepts on a Primary Flight Display for:

- *VMC-like terminal area operations in IMC in a terrain-challenged environment (Approach and Missed Approach)*
- *Complex mountain pass maneuvers (Enroute)*
- *Over a range of specific minification factors*

Develop recommendations for SVS-GA PFD symbology and terrain

Demonstrate application of SVS to advanced operational procedures

Compare qualitative terrain awareness metrics with quantitative data through evaluation of altitude and range estimations for different terrain texturing and minification factors

Research Performed to Date: SD-HDD

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Part A

- Simulated VMC-like approach, missed-approach, and rare event maneuvers, in IMC at Juneau, AK
- 21 Evaluation Pilots (EP)
- Included 16 SVS concepts (4 Terrain x 4 Guidance)
  - Terrain Portrayal Concepts (TPC): BSBG, CCFN, EBG, and PR
  - Guidance Symbology Concepts (GSC): Pitch/Roll Flight Director, Unconnected Box Tunnel, Connected Box Tunnel, and Tunnel with Ghost Aircraft

Part B

- Simulated advanced enroute maneuvers in IMC in a complex mountain pass (Merrill Pass, AK)
- 18 Evaluation Pilots (EP)
- Included 28 SVS concepts (4 Terrain x 7 Guidance)
  - Terrain Portrayal Concepts (TPC): BSBG, CCFN, EBG, and PR
  - Guidance Symbology Concepts (GSC): Pitch/Roll Flight Director, Unconnected Box Tunnel, Connected Box Tunnel, Tunnel with Ghost Aircraft, Crows Feet Tunnel, Ghost Aircraft, and No Guidance

Part C

- Simulated advanced enroute maneuvers in IMC in a complex mountain pass (Merrill Pass, AK)
- Evaluation of the effect of minification and TPC on terrain awareness
- 6 Evaluation Pilots (EP)
- Included 12 SVS concepts (3 Terrain x 4 FOV)
  - Terrain Portrayal Concepts (TPC): CCFN, EBG, and PR
  - Field of View (FOV): 30^{o} , 45^{o} , 60^{o} and, 75^{o}

SD-HDD TPC's

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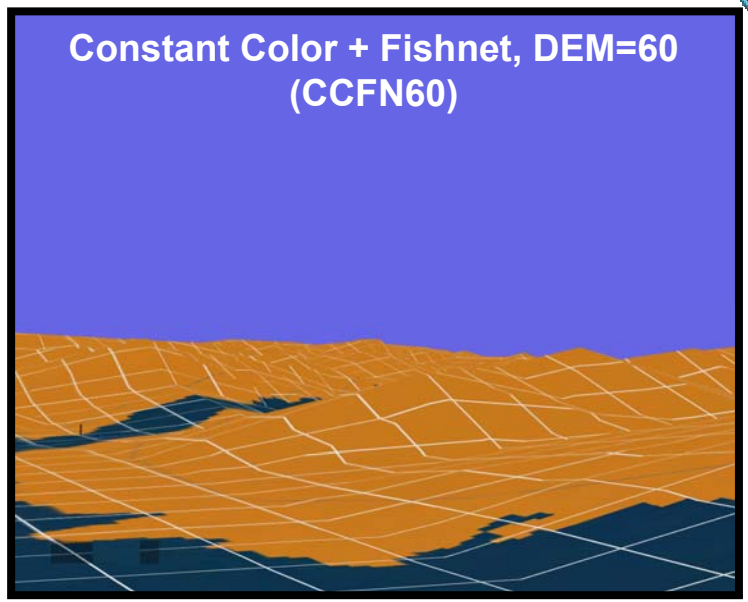
No Terrain, Baseline (BSBG)

Constant Color + Fishnet, DEM=60 (CCFN60)



Elevation-Based Generic, DEM=6 (EBG 6)

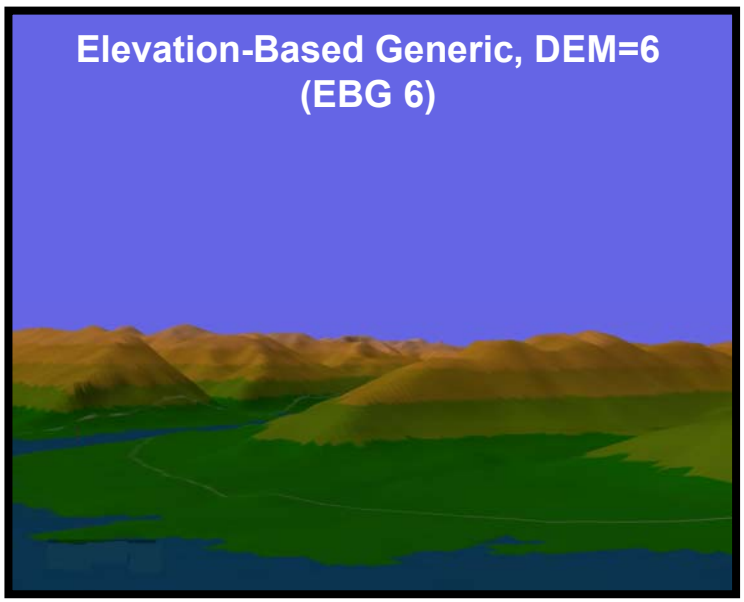
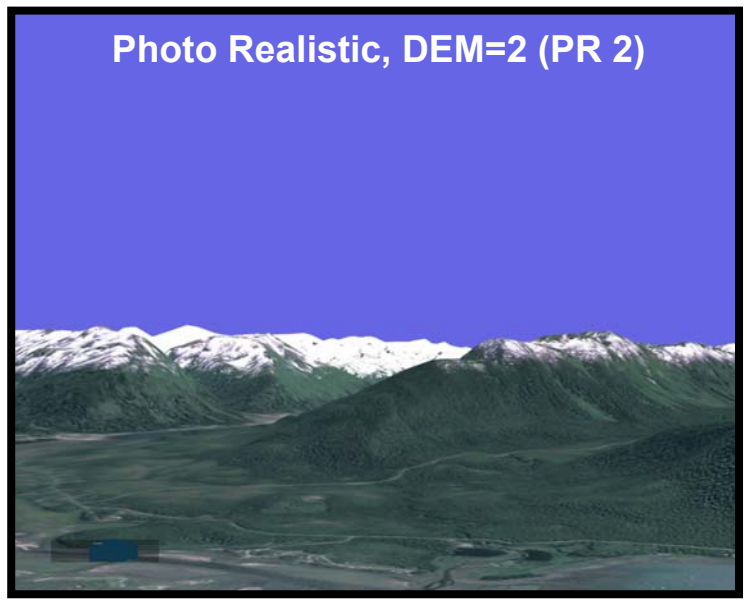


Photo Realistic, DEM=2 (PR 2)



SD-HDD Core GSC's

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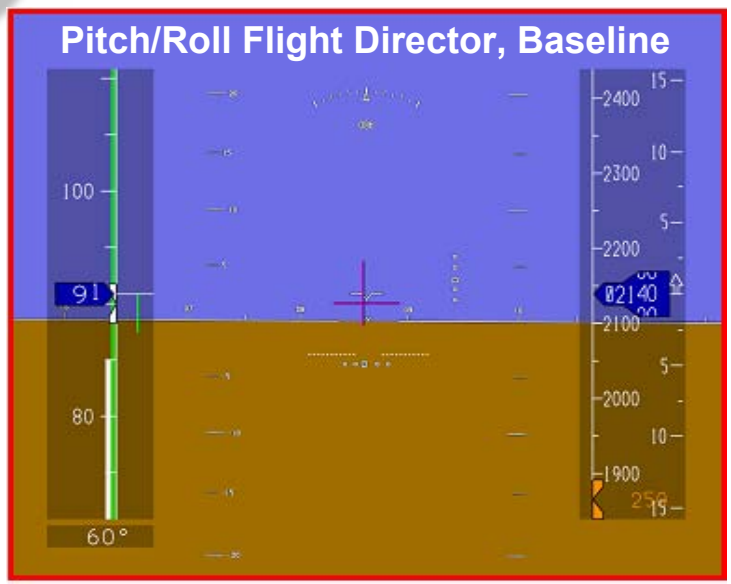
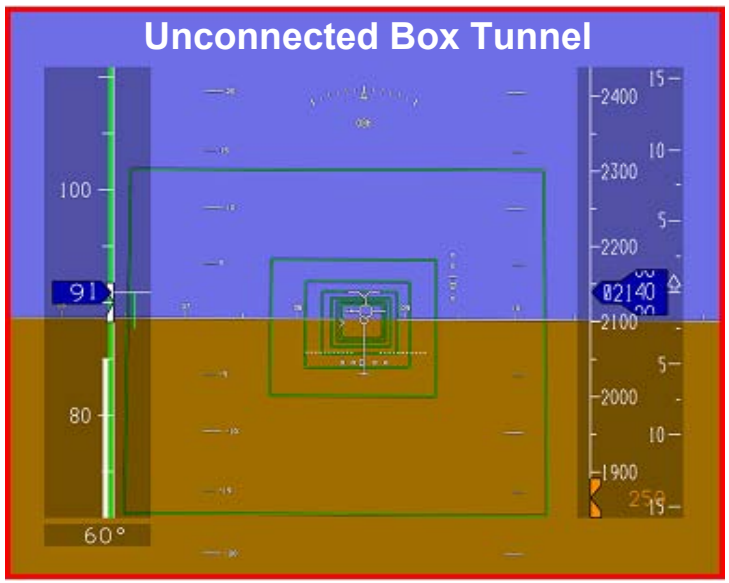
Pitch/Roll Flight Director, Baseline

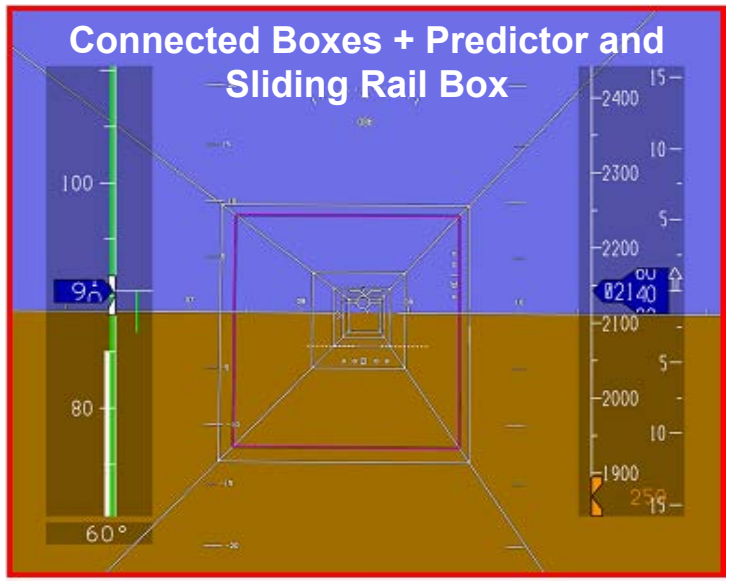


Crow Feet Tunnel + Ghost Aircraft

Unconnected Box Tunnel



Connected Boxes + Predictor and Sliding Rail Box



Research Performed to Date: SD-HDD

Preliminary Results from SD-HDD

Part A (Juneau)

- No interactions exist between TPC and GSC
- GSC's do affect pilot performance
- Tunnel w/ central guidance elements better than P/RFD for these maneuvers
- Depiction of Synthetic terrain improves SA and does not adversely affect pilot performance and workload
- EBG and PR texturing concepts were preferred to BSBG and CCFN

Part B (Merrill Pass)

- No interactions exist between TPC and GSC
- EBG TPC provided best performance
- Most tunnel concepts outperformed P/RFD & were preferred over the P/RFD for this task
- EBG and PR texturing concepts were preferred to BSBG and CCFN
- Depiction of Synthetic terrain (EBG and PR) significantly improved pilot performance and SA and decreased workload

Part C (Merrill Pass)

- No interactions exist between TPC and FOV
- FOV 60 resulted in the highest SA and lowest perceived workload
- FOV 30 resulted in the lowest SA and highest perceived workload
- EBG and PR texturing concepts are preferred to CCFN
- Stress was lowest with FOV 60 and EBG terrain

Several issues challenging the development, certification, and ultimate effective use of SVS display technology emerged

1. Terrain integrity and how increased levels of terrain integrity might enable certain types of operations
2. The lack of comparisons of SVS displays with conventional technology in terms of providing an "equivalent level of safety"
   - Defining "equivalent level of safety" for SVS was mentioned as a key to supporting SVS implementation
   - Scientifically prove improvement in safety
3. Operational fears of SVS:
   - Pilots being induced to descend below Decision Height (DH) or Minimum Descent Altitude (MDA)
   - Continued flight into IMC without proper pilot qualifications due to SVS

Current Research Effort

Equivalent Safety Experiment (ESE)

To scientifically prove that SVS provides a level of safety equivalent to day VFR in degraded conditions such as IMC and/or night by:

- Establishing a metric to quantify “Equivalent Safety” (ES)
- Using the ES metric to compare combinations of display concepts and operations
- Defining guidelines for future synthetic vision systems and their certification process
- Publishing technical reports to increase the public awareness of the benefits of synthetic vision

ESE Simulation and Flight Elements

Simulation

- Perform large-scoped evaluations of experimental display concepts
- Identify critical flight test configurations
- Provide training opportunity for potential flight test subjects
- Establish evaluation criteria for flight test

Flight Test

- Validate critical simulation results
- Extend ground-based test capabilities into a real GA environment
- Implement real-time database integrity monitoring for GA

Notional Equivalent Safety Metric

- The metric will be derived from a combination of a comprehensive set of parameters
  - Qualitative: SART, TLX, CH (or M-CH), SA-SWORD, Safety-SWORD
  - Quantitative: Percent time within acceptable limits, FTE, Workload (steering entropy)
- For the SVS-ESE the metric will look like a results and discussion section of a report
  - Text with data
  - Final score
- Ultimately the metric could look more like a numerical score
  - Result from others using the metric effectively

Design of ESE

- Provides several “safe” points in the data
  - VFR approach in VMC (for several pilot levels)
  - ILS in IMC with baseline round dials (for two pilot levels)
  - ILS in IMC with Single-Cue FD PFD
- Data can help establish ES metric through comparison of effects from several conditions
  - Standard gauges
  - Pathway-based guidance
  - SVS terrain
  - Various pilot levels
- Provide ability to compare display condition/maneuver combinations

Proposed Method

Evaluation Pilots

- Using a spectrum of GA pilots enables:
  - more detailed analysis of the data, a more valid interpretation of results, and higher external validity
  - the establishment of “minimum” levels of ES for various pilot groups

- Total number of pilots is anticipated to be 16
  - The proportion of pilots will be:
    - 50% Low-hour VFR (no IFR training, less than 400 hours)
    - 25% Low-hour IFR (IFR rating, less than 1,000 hours)
    - 25% High-time pilots (IFR rating, 2,000+ hours)

Proposed Method

Proposed Facilities for ESE

IFD/RFD Sim

- Use generic GA model “tuned up” to be C-206 like
- Model force/feel characteristics
- Use 18” SVS-RDs

NASA LaRC Cessna-206

- Combined LCD/mechanical gauge tactical display
- Enable all sim conditions to be tested

ESE Summary

- The Equivalent Safety Experiment is a critical step in SVS-GA research
  - Addresses and facilitates FAA certification criteria currently being created
    - Most major avionics producers either have or are designing a SVS product for GA
  - Provides essential data in terms of measurable operational benefits

ESE Estimated Preliminary Schedule

Simulation begin by:	08/01/2004
Simulation completed by:	09/30/2004
Flight test started by:	01/30/2005
Flight test completed by:	05/30/2005
Reports completed by:	09/30/2005

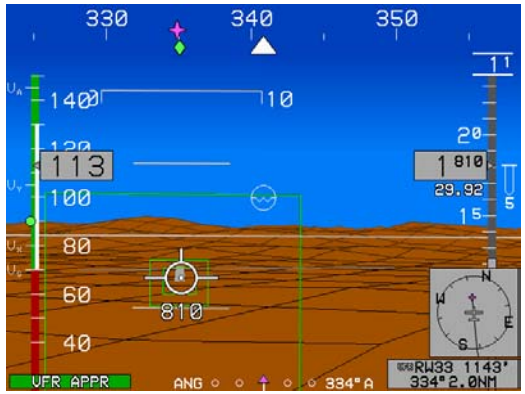
Outside Involvements

Capstone Support

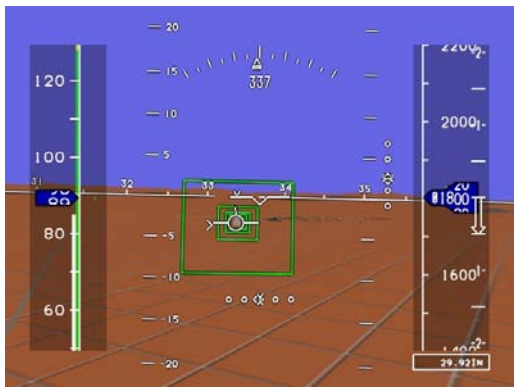
Synthetic Vision Systems - General Aviation: General Overview

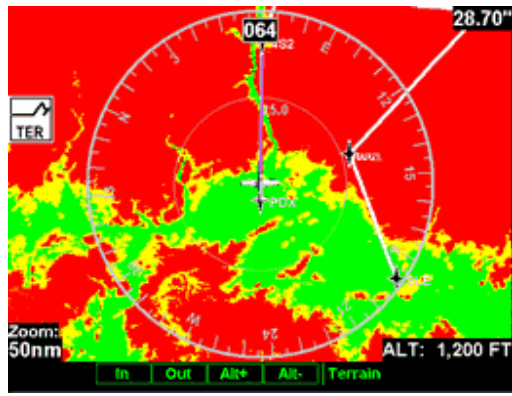
- Effort to equip up to 200 aircraft in Juneau, AK
- Participated in request for proposal development and source selection activity
- Provided technical support
- Included relevant systems in research
  - Chelton style terrain portrayal and tunnel

Chelton SVS PFD and MFD



NASA SVS PFD with UPSAT MX-20 MFD

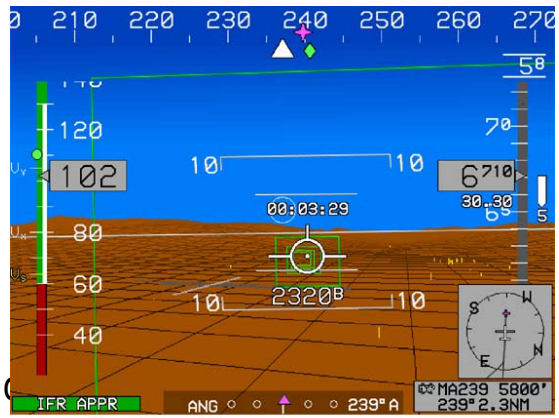




Capstone II Partnership

Synthetic Vision Systems - General Aviation: General Overview

- 3/31/03: Chelton Flight Systems Receives TSO for first generation SVS-GA hardware
- Certification of the system includes the first:
  - GPS/WAAS system that is approved to operate on lower GPS Minimum Enroute Altitudes (MEA's) (opening 41,000 feet of airspace over 1,521 nautical miles of existing routes in Alaska)
  - Certification of Highway-In-The-Sky (HITS) Technology for Navigational Guidance
  - Use of of forward-looking 3-D terrain, atmospheric perspective, & adjustable FOV on PFD
  - Use of advanced HUD symbology on a certified PFD
  - Use of certified dead-stick glide area
  - Use of conformal perspective runway presentation on PFD
  - Use of conformal obstructions on PFD
  - Use of dynamic stall speed indication

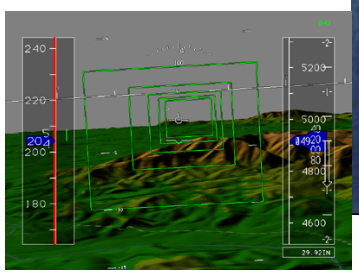


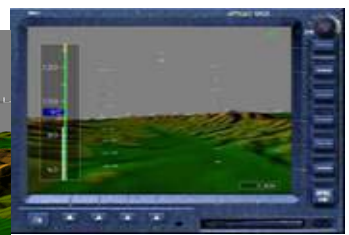
- NASA Participation
  - Participated in Request For Information (RFI) & Request For Proposal (RFP) c
  - Membership on RFP Technical Evaluation Board
  - Conducted two SVS-GA FAA & Industry workshops to transfer research results
  - Directed NASA SVS-GA research towards FAA-requested certification issues
  - Offered Early Expert Opinion on Draft SVS-GA Advisory Circular- due out in 2004

Synthetic Vision Systems - General Aviation: General Overview

Relevance/Justification

Present Synthetic Vision Systems (SVS) are either designed for research or they are very expensive. To find widespread application in GA, SVS needs to be low cost and leverage state of the art COTS technology.





AMPM Program Objective:

- Conduct Human Factors Research and SVS development to provide the GA community with low cost access to the world of SVS using Human Centric Design Methods

Program Tasks:

- Application Research
- Product Research
- Display and Format Research
- Integration into Sim/Aircraft
- Product Refinement
- Flight Tests
- Productization

AM/PM: Low-Cost SVS for General Aviation

Synthetic Vision Systems - General Aviation: General Overview

Application Research

- 327 pilots completed online survey. Most popular features included: Direct To Fix, complete Jeppesen NAV data, approach procedures, wide area augmentation system
- Focus groups studies completed
- Pilots emphasized need for flight planning and flight management tools

Product Research

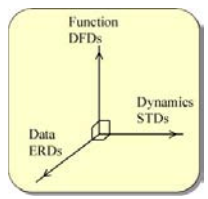
- Possible Displays: Panel mounted display, yoke mounted display, head worn display, low cost HUD
- Possible Platform: Densitron DPX-115
  - Processor Type: Up to 3.4 GHz P4
  - Memory: Up to 2GB of SDRAM
  - Graphics: ATI Radeon Mobility 9600 Pro (OpenGL accelerated)
  - Connectivity: LAN, USB 2.0, PCI
  - Size: 5.7" x 6.8"

Human Factors Research

- Performed on GAWS TOO sim at OPL
- Purpose: Determine the effect of display size, display resolution, field of view
- 8 of 36 pilots completed
- Measure pilot flight technical performance, subjective response, and pilot eye movements

AMPM Product Development

- Based on Tasks 1-3
- 'Product-Like' Design
- Software industry design approach
- Universal Modeling Language (UML)



Dual-Use Science and Technology (DUS&T)

- Cooperative program with the USAF (Air Force Research Labs)
- DUS&T programs need to have:
  - Military Benefit
  - Sound Technical and Management Approach
  - Commercial Viability of Technology
  - Quality of Cost Share
- Pilot Spatial Orientation Enhancements topic
  - Two-year program
  - Substantial NASA support ($$ and technical) (enabling a substantial GA component to the research)
  - Employs SVS display technology (among others, such as tactile cueing) to prevent Spatial Disorientation
  - Rockwell Collins/University of Iowa won the contract
  - Simulation and Flight Test effort
  - July 2004 Kick-Off

DUS&T, continued

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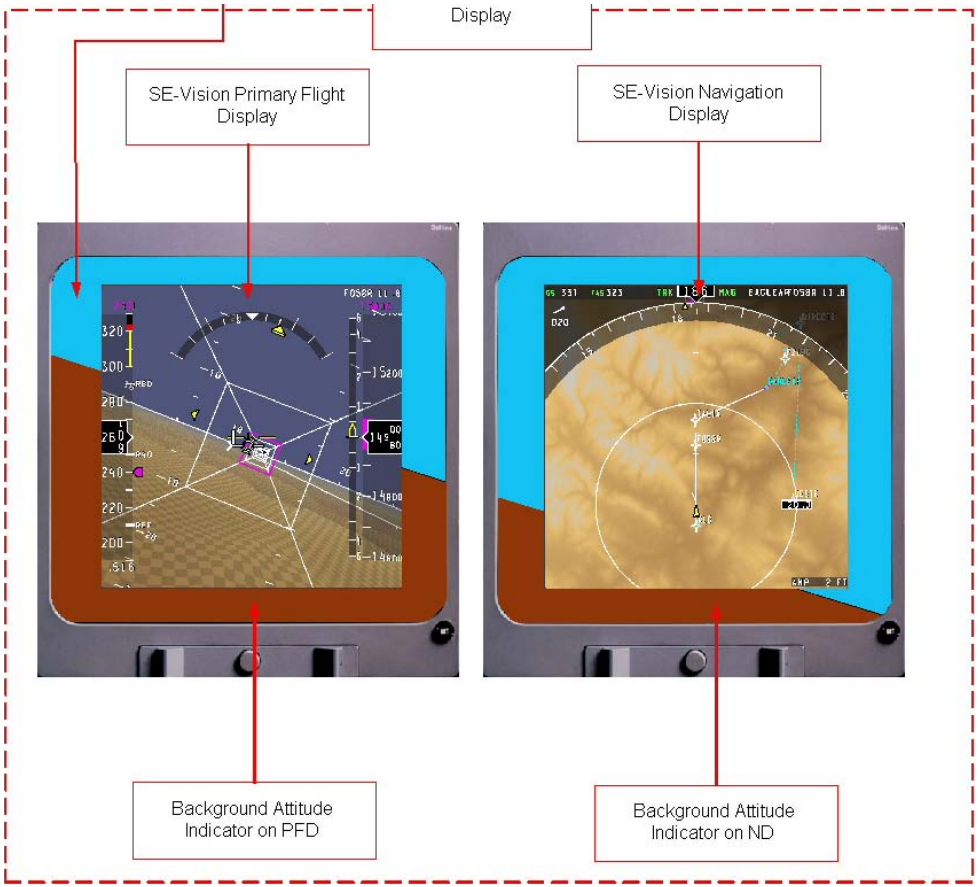


Proposed Display Set-Up

Gyro IPT II

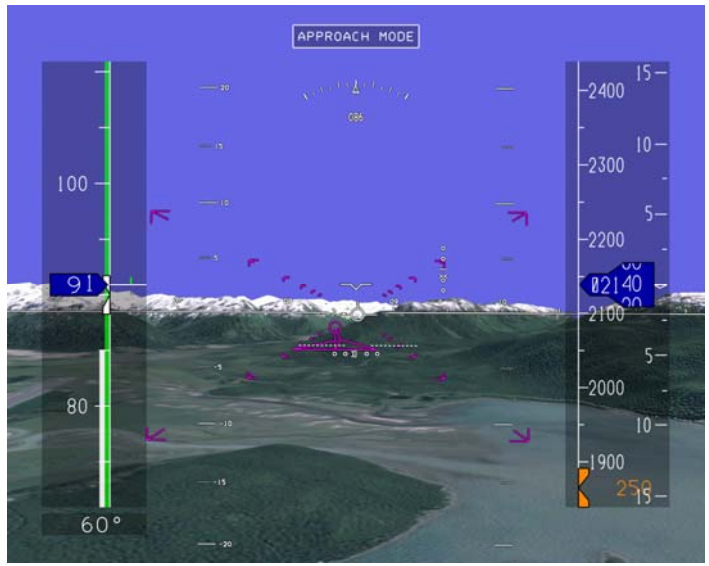
- 4 + 2 Degrees of Freedom Motion Base
- Simulated Cockpit
- PC Control System
- Full function instructor station

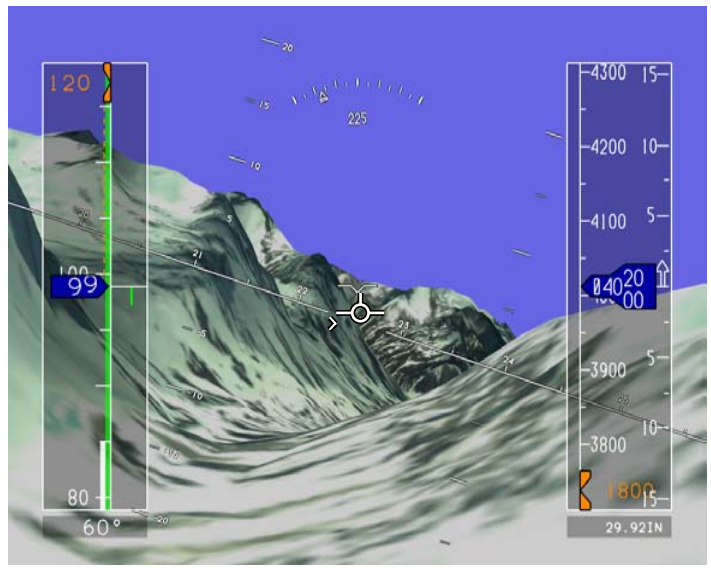
NRC (National Research Council Canada) Harvard Mark IV

SVS-GA Status & Future Plans

Synthetic Vision Systems - General Aviation: General Overview

- The first Synthetic Vision System has been certified by the FAA, and is commercially available for GA aircraft
- Numerous Simulation and Flight studies have established the following:
  - SVS terrain greatly increases total situation awareness while maintaining workload
  - SVS augments and integrates well with advance highway in the sky guidance symbology reducing flight technical error
- Partnerships with the DOD, FAA & Industry:
  - Leverage NASA resources
  - Expedite SVS technology development
  - Lead to SVS product implementation
- FY04 & FY05 will include joint flight tests with: Boeing, Gulfstream, USAF, Rockwell Collins, BAE Systems, Jeppesen, Rannoch, Ohio University, University of Iowa & SATS





Questions and Answers

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